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# A STUDY OF THE GALVANIC SKIN RESPONSE AS A MEASURE OF HUMAN ENERGY EXPENDITURE

A THESIS

Presented to

The Faculty of the Graduate Division

by

Francis Knapp Horton

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# SUMMARY

This study summarizes the significant physiological methods that have been used to study and measure both work and fatigue. An experiment involving the middle finger segment of the *extensor digitorum communis* in an isometric contraction of sustained extension was carried out at four levels with four subjects in order to test the suitability of the Galvanic skin response as a measure of human energy expenditure. The experimental design utilized involved the determination of the correlation between a subject's integrated electromyogram and his Galvanic skin response as measured by a modified strain gage bridge. An attempt was made to establish a functional relationship between the integrated electromyogram and the Galvanic skin response.

The integrated electromyogram was chosen as the independent variable on the basis of the research reported by Lippold (25) and Lippold, Redfearn and Vuco (26). The skin conductance of each subject was recorded before and after each trial. The two variables analyzed were the frequency of integration per minute of the electromyogram and the deflection of the Galvanic skin response in millimeters on the strain gage. Permanent records were made of the variables by means of a Honeywell model 1508 Visicorder. The correlation coefficient was calculated for each trial and the data fitted to six different functions by means of a least squares curve fitting computer

program. An index of goodness of fit was produced for each function and the function with the greatest value for this index considered the "best" fit to the actual data.

Analysis showed the correlation coefficient for the two variables to range from 0.21 to 0.89. All trials were fitted best by either a linear or hyperbolic function but the goodness of fit for each trial was so poor that it is impossible to make any positive conclusions regarding the suitability of the Galvanic skin response as a measure of human energy expenditure. The results obtained also imply the inadequacy of the integrated electromyogram as a generally useful measure of human work.

One primary problem encountered was the high variability among subjects with respect to the muscle activity necessary to produce the same work output. Subjects varied extensively from task to task even though all four tasks involved the same operation at different levels of difficulty. Muscle tremor contributed a significant error to the electromyogram in a number of trials. Recommendations include suggestions for possible improvements in the operation of the integrated electromyogram as a measure of human energy expenditure.

# CHAPTER I

## INTRODUCTION

The measurement of work or fatigue by physiological means has long been an unattainable ideal because of incomplete knowledge of the physiological effects of work on the human organs or the mechanisms involved in the generation of fatigue. Measurement of the physiological effects of work on the organs is desirable because of its ability to give quantitative interpretations to what has previously consisted of subjective interpretations of effort (1). This thesis reviews some of the major developments in physiological work measurement and presents an experiment involving two possible approaches to finding a valid and reliable measure of energy expenditure.

Investigated in this study are the Galvanic skin response (GSR) and the integrated electromyogram (EMG). This study was suggested by previous work at the Georgia Institute of Technology (2,3) and was aided by the availability of the research facilities of the Department of Physical Medicine and Rehabilitation of Emory University located at Grady Memorial Hospital in Atlanta, Georgia.

The objective of this research was to investigate changes in the GSR during isometric exercises and determine if these changes bore any relation to changes in the integrated EMG, which has already been well correlated with work output (24,25,26). An isometric task may be defined as a task involving a muscle contraction in which there is no appreciable change in the length of the fibers of the muscle (4). No attempt was made to hypothesize any causal relation or physiological interaction between the two records. The experiment consisted simply of a correlation between two physiological variables recorded simultaneously.

In order to provide the reader with a reasonable background knowledge of some of the historically significant attempts at physiological work measurement a literature survey is included in this review. Among other things, it will make the reader aware of the many problems encountered in trying to make such measurements. Included in the literature survey are discussions of the electromyogram and the Galvanic skin response.

# CHAPTER II

# LITERATURE SURVEY

## The Ergograph

The erogograph was one of the earliest instruments used to demonstrate the nature of muscle fatigue. As early as 1904, Mosso (5) was recording "ergograms" of his subjects. The instrument was designed to isolate as small a muscle group as possible and measure the effects upon that group of a paced task. By means of a simple mechanical device the raising and lowering of a small experimental weight was recorded on a rotating drum. The weight was raised and lowered to each beat of a metronome. After usually a short time the distance which the subject could move the weight was greatly reduced and a corresponding recording on the drum furnished a permanent recording of his becoming fatigued.

Lehman (6), using the information obtained from ergograms, suggested the existence of three types of individuals:

> 1. The "energetic" who produces a curve in which at the beginning of the strokes maintains a high level then decreases slightly or even increases, and finally gradually drops to a lower level which is maintained for some time before the point of exhaustion is reached.
>
> 2. The "an-energetic" who produces a curve that drops steadily and steeply and then maintains a low level before exhaustion.
>
> 3. A normally energetic or fatigable type of individual whose curve shows a rapid and more or less regular drop associated with a gradual accumulation of fatigue.

Based on these facts, Viteles (7, p. 444) has suggested that while no direct use can be made of the ergograph technique in industry, adequate testing of the individual before employment might be accomplished. This would theoretically enable the employer to place the individual according to his abilities as regards repetitive or intermittent tasks.

## The UNOPAR

The Universal Operator Performance Analyzer and Recorder (UNOPAR) is a device developed by Nadler and Goldman (8) that may be used to determine what method requires the least motion to perform a given task. They call it the first device to measure the actual structure of work. They say, "Now it is possible to learn what actually occurs in the physical performance of a job." The claim is made that with the device it is possible to measure most of the aspects of work and to find out the true effects of all the factors affecting the work.

In the UNOPAR a 20,000 cycle per second sound source is placed on the worker's hand and three microphones pick up the sound as a point on a three dimensional coordinate axes. Individual recordings from each microphone represent one component of a motion vector. The recordings are analyzed using known Doppler effect phenomena to give velocity, acceleration or deceleration, position in space, distance and time of the recorded motion.

## The Effort Detector

The Effort Detector or "Force Platform" as it is popularly known is very similar in application and function to the UNOPAR. As developed by Lauru (9), the Effort Detector makes use of the properties of piezo-electric quartz and translates variations in pressure into proportional variations in an electric current. The Detector registers in the three component planes the reactions caused by muscular efforts brought into play in the execution of a movement. These are recorded, after amplification, on oscillographs and a permanent record of the oscillations made with a five lens camera. A detailed description of such a platform may be found in Greene and Morris (10,11) who have used the device widely in this country.

Lauru (9) has used the Detector to select the motion pattern requiring the least amount of physiological costs from among possible patterns that could accomplish the same task. Hudson (12) has used the device to find the correct dimensions for certain workplaces.

## Carbon Dioxide Measurement

The first truly physiological measurement of fatigue and effort was a direct metabolic test of the effects of activity. Apparatus developed for this test consists of a one way valve and face mask which allows the subject to breathe atmospheric air but channels his expired air into a large bag usually carried on his shoulder or back (13).

The quantity of carbon dioxide ($CO_2$) produced by an individual as a by-product of his metabolism while performing some task was thus collected and could be analyzed to obtain what was considered to be a direct measure of the fatigue produced. It was necessary to obtain a basal $CO_2$ output rate for each individual while in a resting state to determine the increase in $CO_2$ output which occurred with work.

While this technique can be used in many industrial situations the method itself still leaves much to be desired. In order to obtain a sufficient sample of expired air, the apparatus involved is quite bulky and troublesome to the operator. Further, the analyses involved are tedious and time consuming.

At one time it was suggested that normal times for operations be set up on the basis of $CO_2$ output or oxygen consumption per unit time or per unit operation (14). This suggestion has been completely abandoned in favor of simpler, less cumbersome techniques. However, many of the newer indirect measurements have been shown to correlate highly with this direct metabolic measurement.

## Pulmonary Ventilation Rate

In response to the difficulties involved in the $CO_2$ method, researchers at the Max Planck Institute of Work Physiology in West Germany have devised an improved but similar method of measuring effort and energy expenditure in man (13). This technique is based on the human pulmonary ventilation rate, the volume of pulmonary air expired by an individual expressed in liters per minute.

Through their work the collecting bag has been replaced by a light-weight gasometer prepared especially for this application. This device is described in detail in Greene, Morris and Weibers (13). Further simplification was achieved through the use of various automatic machines to test the composition of the expired air.

In using this test, it is necessary to establish a base line for each subject while he is at rest. The experimental procedure utilized by Dudek and Petruno (15) involves establishing this base line and then reading the gasometer at one minute intervals and recording the differences in readings. This yields what they call the "uncorrected ventilation rate." These figures are then adjusted to standard temperature and pressure (dry) and are used along with the analysis of the chemical composition of the expired air to determine the "caloric value" remaining in the expired air. From this a rather reliable and valid measure of the physiological cost of work can be made. Lehman (6) has shown the method to work well with dynamic tasks and Dudek and Petruno (15) conclude from their pioneer studies of sedentary work that pulmonary ventilation rate offers a practical technique of measuring the physiological cost of work.

## Chemical Changes

It has long been known that chemical changes occur within the organism after both sedentary and dynamic work (16, p. 98). Though changes occur in the endocrine glands, the chemistry of the alimentary canal and other secretions (7, p. 453), blood and urine chemistry have received the majority of study.

Blood chemistry changes taking place during work offer one of the most complete and plausible explanations of fatigue available today. As muscular activity goes on, the energy producing material glycogen is burned up within the muscles yielding lactic acid as a waste product. Lactic acid may be reconverted into glycogen in the presence of oxygen but in a case of even moderate sustained activity, oxygen cannot be supplied to the muscles at a fast enough rate. Such a situation soon leads to an excess of lactic acid within the particular muscle group involved and this excess spreads into other areas of the body. Lactic acid, being a strong reagent, seriously interferes with continued muscle activity and is thought to be the major reason work curves decline with time. Locally, lactic acid is thought to back up until there is not enough fuel left for the muscle to burn. Excess which is conveyed throughout the body is thought to be the main cause of the "feeling of tiredness" accompanying activity (7, pp. 450-451).

## Circulatory and Cardiac Measurements

Various scientists have measured blood pressure, pulse pressure, heart rate, pulse rate, pulse product, and heart sound in attempts to measure the physiological cost of work. These studies have been spurred by small and remote recording instruments such as the pulse recorder designed by researchers at the Max Planck Institute.

Heart sound has been found to be an unusable variable by Schwartz (3) and Ekey and Hall (2). The problem is simply that the heart sound cannot be satisfactorily segregated from extraneous noises such as breathing and talking on the part of the operator and distracting noises such as those existing even in the laboratory.

Blood pressure and pulse pressure (the difference between the systolic and diastolic blood pressures) have also been studied. Brouha (17), Ekey and Hall (2) and Smith (18) all concluded that the variability of blood pressures from individuals both from time to time and between individuals is so great as to render blood pressure virtually useless as a reliable measure. Schwartz (3) has found no significant variance, however, for pulse pressure among subjects and suggests that it might be a useful index of fatigue. Later results of Smith (18) do not agree with this finding.

Brouha (17) has investigated pulse rate and both pulse product and pulse rate have been studied by Lovekin (19). Graphically these two variables were shown to have quite similar distributions over time and further, these curves are very much like the daily output curves found in industry.

The most recent and thorough investigations into the physiological measurement of work have centered around the heart rate. Heart rate has been found to be affected by work load (height and weight of work and rate at which it is done), temperature, humidity, kind and amount of clothing, sex, age, state of nutrition, physical condition, how long since eating or smoking, time of day, self consciousness and emotional state, accumulated fatigue and training (20).

Nichols and Amrine (21) used heart rate as an indicator to test various "Principles of Motion Economy". By means of a conventional portable electro-cardio-machine and a recording-radio-tachometer built for the Athletic Department of Purdue University they established that heart rate was in fact a valid measure of the difficulty of work. They went on to show "proof" of the truth of certain of the "Principles of Motion Economy" (22).

Their criterion was the smallest increase in the number of heart beats per minute above the resting rate of the individual test subject. This rate was determined by having the subject assume the position in which he was to work and resting for a period of time before his heart rate was recorded.

Brouha (17) has devoted considerable attention to heart rate. He has been primarily concerned with the construction of "heart rate recovery curves". His method consists of counting the pulse rate for 30 seconds at three one-minute intervals during the first three minutes of the recovery period after the termination of work and while the subject is sitting quietly. The curve plotted from the pulse rate data indicates the actual values of the pulse and its rate of recovery to its resting level. The heavier the physiological load the higher the heart rate and the more slowly it returns to its resting level.

Brouha has been interested particularly in heart rate recovery as a means of evaluating job factors which contribute to fatigue. He has shown that not only is heart recovery a measure of effort in one work period but that it also shows the rapid accumulation of strain that occurs with repeated cycles.

Young (20) has investigated the possibility of using heart rate as an objective method for rating operator performance on jobs of varying physical difficulty. He concluded that there was a correlation between heart rate and pace for individual subjects and proposed that heart rate might be used to rate operator performance after further research.

## Electromyography

Since physical work is performed by the use of muscles it seems reasonable that measuring muscle activity might give some quantitative information to the researcher about fatigue or physiological cost of work to an individual. In the last twenty years with the development of Electromyography this has become possible.

Electromyography (EMG) is the monitoring and recording of skeletal muscle at rest and during contraction. Associated with any voluntary muscle contraction is an electrical change which is reflected in the production of a wave of depolarization or negativity. The electrophysiological basis of EMG is the recording and interpreting of these changes in skeletal muscle (23).

As fatigue is generated in muscular work, it is quite apparent that the amplitude of the EMG signal increases and that there is a decrease in the frequencies of the potentials. The EMG also develops a rhythmic sinusoidal variation as fatigue is built up (24). In studies, these changes have been attributed to an increase in elementary electrical activity at a given time and grouping of motor unit discharges. In efforts of high output it has been shown that there is an increase in the number of motor units discharging to maintain a constant output while grouping of discharging also occurs (26). It appeared to Scherrer and Bourguinon (24) that a deficiency in the coupling of the electrical and mechanical phenomena within the muscle on the one hand and a sychronization of the discharges of the motor units on the other were the two essential EMG phenomena appearing during every prolonged and intense activity associated with the muscles.

It has been found that under limited conditions of less than maximal tension there exists a linear relationship between the integrated EMG and tension produced by a voluntary isometric contraction in a human muscle. Integration was performed in all experiments by an electronic integrator such as that used in this experiment and the correlation coefficients in that research consistently fell between 0.93 and 0.99 using the gastrocnemius - soleus muscle group of the right leg with the right foot in plantar flexion (25).

In varying tension it has been shown that changes in the strength of muscle contraction are brought about in two ways. As the strength of the contraction becomes greater the number of motor units that are active becomes greater and there is an increase in the frequency at which these active units contract. Above the maximum tension possible in the muscle there is supramaximal stimulation of the motor nerve and all motor units are active furnishing a constant level of electrical activity that will not be surpassed. This is called "saturation" of the muscle (25).

While the amplitude of the EMG is a function of the number of active motor units rather than their frequency of discharge, the integrated EMG would appear to be dependent on both factors. There is no direct proportionality between the mechanical and electrical responses of a single motor unit but when the summated effects of a large number of units are recorded by surface electrodes from the whole muscle, the variation between the two is effectively cancelled out (25).

The Galvanic Skin Response

Research with the Galvanic skin response (GSR) by Ross, Dardano and Hackman (27) has suggested that high skin conductance levels are related to high vigilance levels in routine vigilance tasks. Later work by Ekey and Hall (2) and Schwartz (3) suggest the possibility of the GSR, or change in skin surface conductivity in response to some external stimulus, being a useful and valid tool in the appraisal of the physiological cost of work to man.

Ekey and Hall found that skin surface conductivity increased linearly over time at all experimental levels considered. At that time there was no satisfactory explanation for that unique result. (All such time relations for other physiological variables had varied quadratically.) It was theorized that such a GSR is related to electrochemical changes in the muscles. It is well known that the lungs and circulatory system have limited capacities for supplying oxygen to the muscles which sets a limit on the steady state of energy production in times when energy is expended. Thus, it was theorized that physiological factors which compensate for initial, peak and terminal work cycle energy debits of muscles might relate to the GSR.

The results obtained by Ekey and Hall for GSR during rest periods showed a distinct lack of recovery to a "normal" level of conductance. To them this suggested an analogy of both the "long" and the "short" of physiological fatigue. The existence of multistage physiological activities within the organism to accommodate various physical demands was suggested. The human heart might be seen as a "generator" which cannot compensate directly for the total energy required of the organism during a given period of work. One requires rest to "recharge" the battery and the human system.

Recent (1966) research summarized by Montagu and Coles (28) attributes the GSR solely to sweat gland activity. The resistance of the body interior is negligible compared to the resistance of the stratum corneum skin layer. This layer is perforated by sweat ducts that offer active or potential conducting pathways for electric current.

The electrical model (Figure 1) developed by Thomas and Korr and supported by the work of Lader and Montagu (29) provides for the linear increase in conductance with the number of active sweat glands and includes the resistance of the body interior and a small skin capacitance which is measurable only with A.C. methods.

This does not mean, however, that the GSR is only a sophisticated means of measuring perspiration. Actually it is an extremely sensitive variable capable of reacting to a very small physical or emotional stimulus (28, 30). Much of the current research with the GSR considers the phenomenon as an instantaneous reaction to a single and unique stimulus. This study is concerned with a slightly different aspect of the GSR. The variable of concern is the long term change in the skin surface conductance produced by an isolated muscle task.

Accurate measurement of the GSR is difficult and there is a very great number of devices mentioned for it in the literature. The greatest single problem encountered is that of polarization. At any time a D.C.

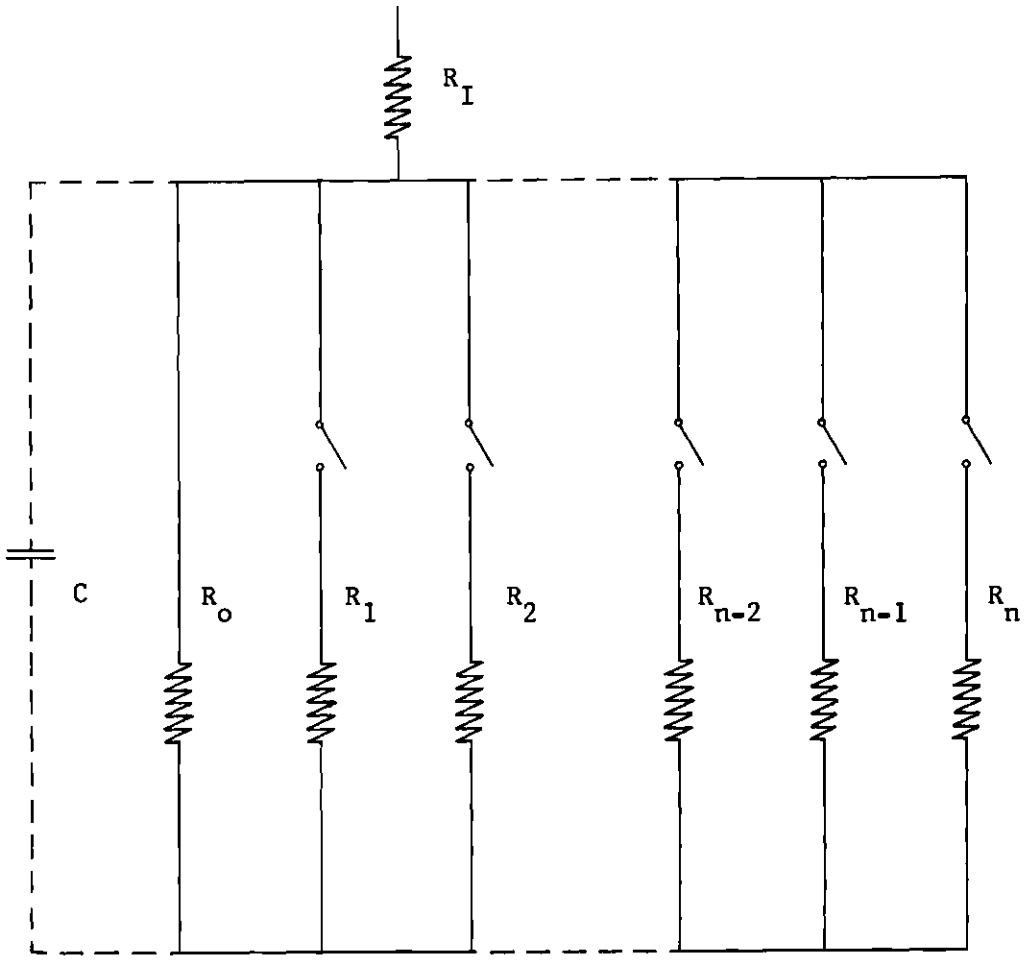



Figure 1. Electrical Model of Organism in Relation to the GSR.

($R_o$ = Resistance of dry skin, $R_I$ = Resistance of body interior, $R_1$ - $R_n$ = Resistance of secretory units, C = skin capacitance)

(from Montagu, J. D. and E. M. Coles, "Mechanism and Measurement of the Galvanic Skin Response," Psychological Bulletin, 65, No. 5, pp. 261-279, (1966).

current flows from a metallic conductor to a saline solution an e.m.f. is generated in opposition to the current flow. This acts as an apparent resistance in series with the resistance of the subject. There are a number of solutions offered to this problem that have been tried with unclear results by a number of researchers (28). The most curious aspect of the problem is that if readings are taken over an extended period this effect is no longer significant and may be ignored (30).

The GSR is not influenced by random artifacts of movement and can easily be monitored over long periods of time. Factors which may affect the GSR are: temperature, humidity, time of day, age, sex, race, personality traits, intelligence, habituation and adaptation, mental health, physical condition, bodily activity and mental work (28).

# CHAPTER III

# INSTRUMENTATION

## GSR Measuring Device

The GSR measuring device utilized in this experiment consisted of a simple D.C. strain gage and amplifier. In order to cut the applied voltage to an acceptable level 33-K one per cent resistors were placed in the circuit in the bridge drive legs of the circuit (28). In order to monitor the values of the subject's resistance and therefore, conductance, a microammeter was placed in series with the subject and a voltmeter in parallel as shown in Figure 2.

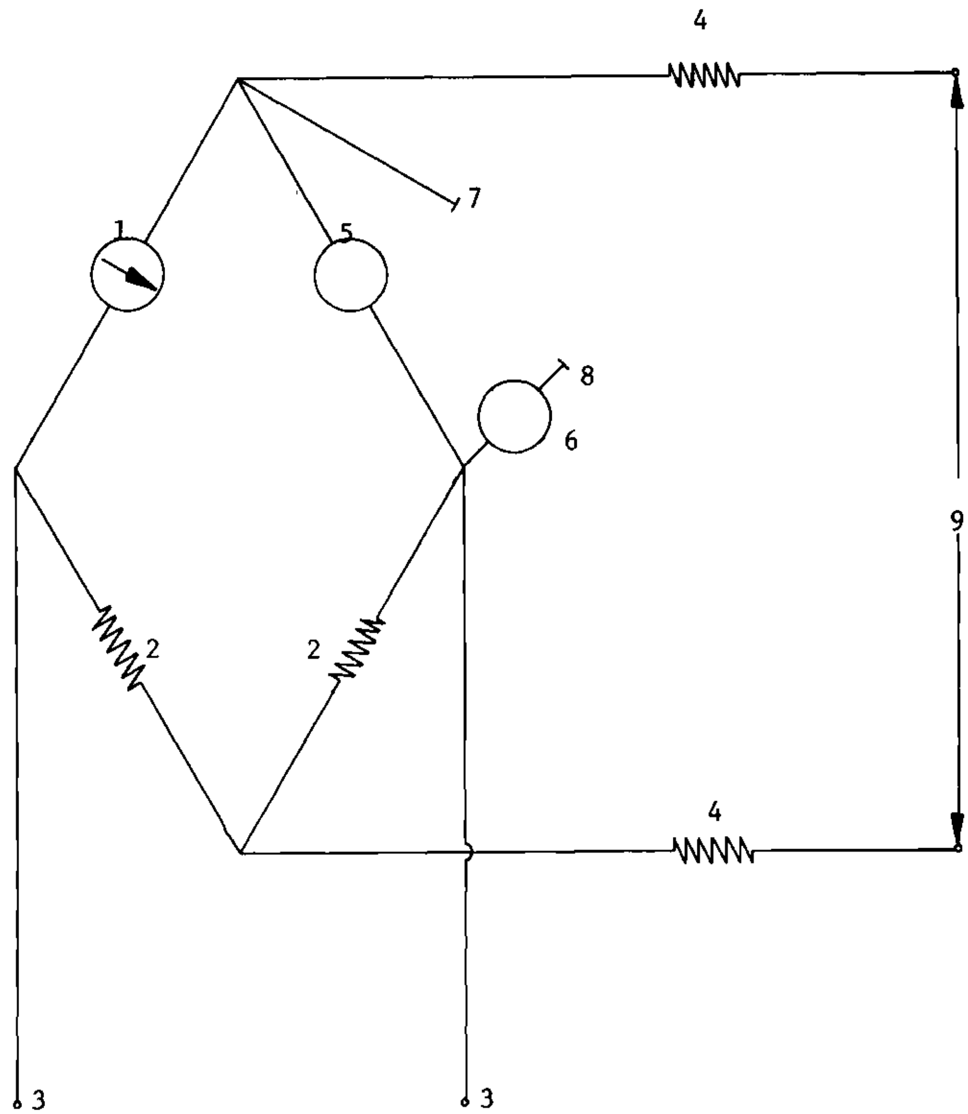
## Experimental Equipment

The equipment utilized in this experiment consisted of the following:

Honeywell model 1508 Visicorder 12 channel recorder

TECA "Medelec" consisting of:

| | |
|---|---|
| C6/4 | Camera and Display Unit |
| MS/3 | Amplifier and Stimulator |
| FA3 | Frequency Analyser |
| P3 | Patching Unit |
| I3 | Integrator |
| SG3 | D.C. Strain Gage Amplifier |
| FM3/4 | Tape Recorder |




1. Helipot Model A 500K 10 turn precision potentimeter
2. 52K 1% ceramic resistors
3. Input signal to SG3
4. 33 K 1% ceramic resistors
5. Simpson 260 voltmeter
6. Olson ME-100 microammeter
7. Proximal } Subject electrodes
8. Distal } Subject electrodes
9. Bridge drive ( $\pm$ 5V from SG3)

Figure 2. Schematic Diagram of the Strain Gage Bridge Used in Conjunction with the SG3 of the Medelec to Measure the GSR.

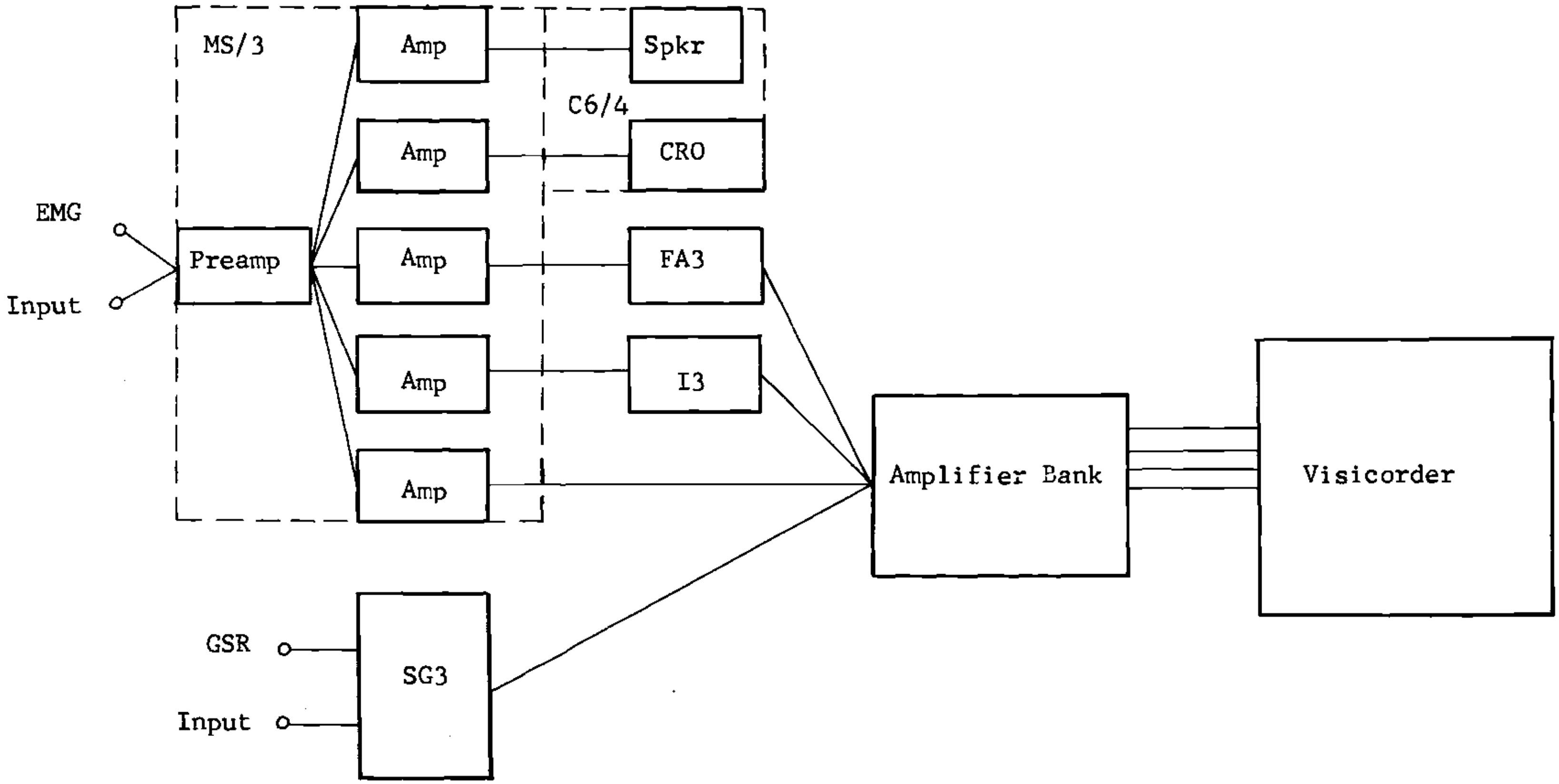



Figure 3. Schematic Diagram of Medelec and Visicorder as Used in Experimental Trials.

INCOR 8 Channel Amplifier Bank

Other equipment consisted of:

Meylan Decimal Minute Stopwatch

EKG Sol (Burton, Parsons & Company)

100, 200 and 500 gram Cenco Laboratory Weights

Grass Zinc Skin Surface Electrodes (1 centimeter)

Taylor Weather Station

Stretchable Adhesive "Band - Aid" Tape

# CHAPTER IV

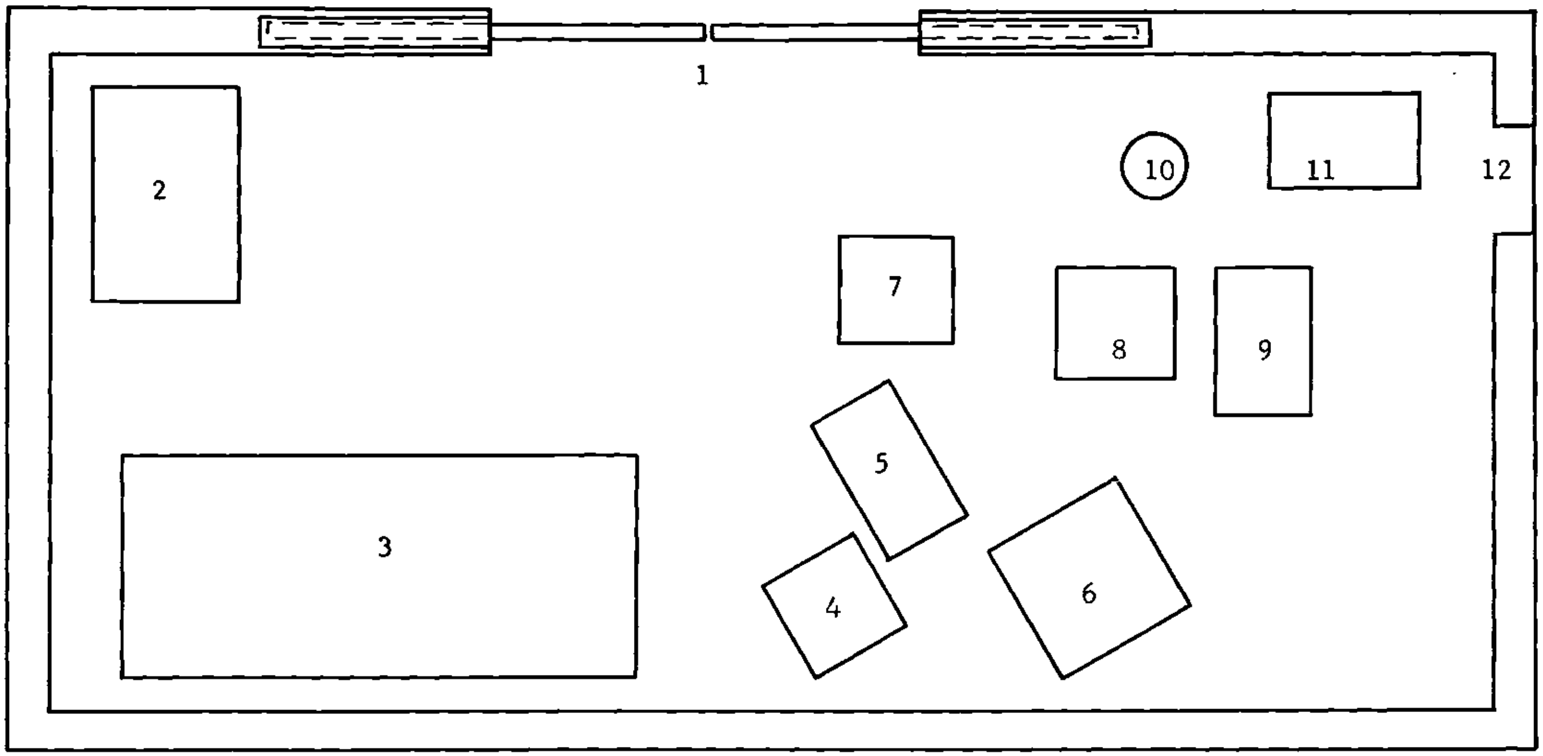
# EXPERIMENTAL PROCEDURE

## Environmental Conditions

All of the experimental trials were carried out during August, September and October, 1967, between the hours of 9:00 A.M. and 9:00 P.M. Each subject was allowed to choose the time of day at which he would appear. The particular task undertaken at any time was selected by means of a table of random numbers.

All trials were carried out in a specially designed windowless room on the ground floor of Grady Memorial Hospital in Atlanta, Georgia. Due to the sensitivity of the EMG to random radio influence and A.C. interference this room is completely electrically shielded. The walls, ceiling, floor and glass in the three recessed light fixtures all contain sheets of copper screening. The two piece door slides on a grounded brass strip.

Power is supplied to the room from an isolated transformer. The actual electrical outlets serving the equipment are located in the next room. Wires to the individual pieces of equipment are run through the small opening in the northern wall of the room. The room is twenty feet by nine feet and peach in color up to a height of sixty inches, the remainder being beige with a white ceiling. The principal dimensions are shown in Figure 4. Every item in the room, except the table and the




1. Door
2. Drawing Board
3. Hospital Bed
4. Subject
5. Table with GSR Bridge
6. Medelec
7. Researcher
8. Researcher
9. Visicorder
10. Gooseneck Lamp
11. Rack
12. Power Supply Window (11" x 11")

Figure 4. Scale Diagram of the Experimental Room Where all Trials Were Performed.

(Scale 3/8" = 1')

Figure 5. Medelec and Visicorder as Used in Experiment.

drawing board, is fitted with casters.

All experimental trials were carried out with the overhead lights out and only the gooseneck lamp and lights on the equipment in operation. During the trials the relative humidity ranged from twenty nine per cent to sixty per cent, the temperature from 21.7 to 27.8 degrees centigrade and the barometric pressure from 29.71 to 30.26 inches of mercury. These records were made simply to observe any wide changes that might occur in the GSR or basal conductance levels during the trials and perhaps offer some explanation for any changes. While it would have been desirable to have an experimental room with temperature and humidity controls, no such room was available.

## Subjects

In order to use only subjects who could be expected to exhibit normal EMG patterns and GSR, all subjects were male undergraduate students at the Georgia Institute of Technology between the ages of nineteen and twenty-four years. All subjects reported no history of muscle, nerve, skin or vascular disease that might somehow alter the behavior of either variable.

Any adverse psychological reaction on the part of a subject to the experiment would very likely produce a GSR indicative of mental as well as physical stress and the recorded GSR in such a case would not be a reliable measure of simple physical stress. In order to minimize any reaction that might arise from apprehension, subjects were chosen from students already known to the investigator. Their familiarity with the investigator was intended to allay most of their uncertainty about the experiment which might have otherwise had a distinct effect on the observed GSR masking the physical response to the experimental task. All subjects were fully informed of the purpose of the experiment.

## Tasks

Four tasks were utilized in the experiment. These were intended to cover the range of normal stress on the middle finger and the extensor digitorum communis of the subject's dominant arm. Task I involved a contraction of sustained extension of the muscles of the hand with the fingers spread wide apart. This was used to represent the situation of voluntary contraction for the extensor when no weight was held.

Tasks II, III, and IV consisted of suspending weights of 200, 300 and 500 grams, respectively, by a fourteen inch string from a loop over the middle finger between the distal and proximal interphalangeal joints. The subject was required to hold the finger at a constant height and his attention was directed to not allowing the finger to tremor.

In order to eliminate any interference from extraneous muscle activity or movement, the subject's forearm was placed on the arm of his chair with his wrist and hand forward of the chair arm. This provided support for the arm but none for the hand or finger used in the experiment.

## Electrode Placement

After the subject was seated, his dominant arm was cleaned with an alcohol swab and the styloid process of the ulna of that arm scraped with a small emery board. This area functioned as the inactive distal electrode site for the GSR measuring device. The scraping of the skin surface at this point served to remove the majority of the stratum corneum at this point so as to include only one thickness of this layer in the actual GSR circuit and approximate the circuit shown in Figure 1. This is desirable since the GSR mechanism works solely through the sweat ducts present in the stratum corneum.

The two EMG electrodes were located over the middle finger segment of the belly of the <u>extensor digitorum communis</u> of the dominant arm approximately one centimeter apart. This area was located by palpating in the general area for the strongest contraction occurring when the subject raised and lowered his middle finger or pushed it up against a solid object. After EMG electrode placement, the response was monitored on the electromyograph to verify that the measured activity was originating with the middle finger rather than another segment of the extensor. The proximal GSR electrode was located approximately one inch toward the wrist on the muscle from the closest EMG electrode.

It was necessary for consistency and accuracy that the GSR eletrodes have the same orientation in the bridge circuit at every trial. Reversing the direction of current flow would produce an apparently nonexistent change in conductance. For this reason in each diagram of the GSR apparatus both the proximal and distal electrode positions are identified (28).

Prior to application, each electrode was lightly smeared with EKG

Sol, a commercial electrode paste. The electrodes were secured with stretchable adhesive tape designed for the purpose of holding electrodes to the skin surface.

## Recording

After all electrodes were in place the EMG and GSR bridge were turned on and the bridge balanced. No recording was made at this time and the subject was required to sit quietly until his EMG showed him to be relaxed and his GSR reached a steady state. In some subjects it took as long as ten to fifteen minutes for the GSR to reach a steady state. In most instances this reaction could be attributed to apprehension on the part of the subject. Loose electrodes, some malfunction of the GSR equipment or a stray ground could also produce an erroneous GSR reading.

After acclimatization, the GSR bridge was balanced to the zero point and the weight positioned on the subject's finger. Recording was begun at this time and timing begun with the stopwatch. Recorder speeds used were 100 millimeters per second and 0.25 millimeters per second. Analysis was made only of the recordings made at the fast speed where intervals of one tenth of one second were marked off by the timing mechanism of the Visicorder. Trials ran until no further change could be detected in the GSR or the subject's GSR produced a full-scale deflection on the strain gauge.

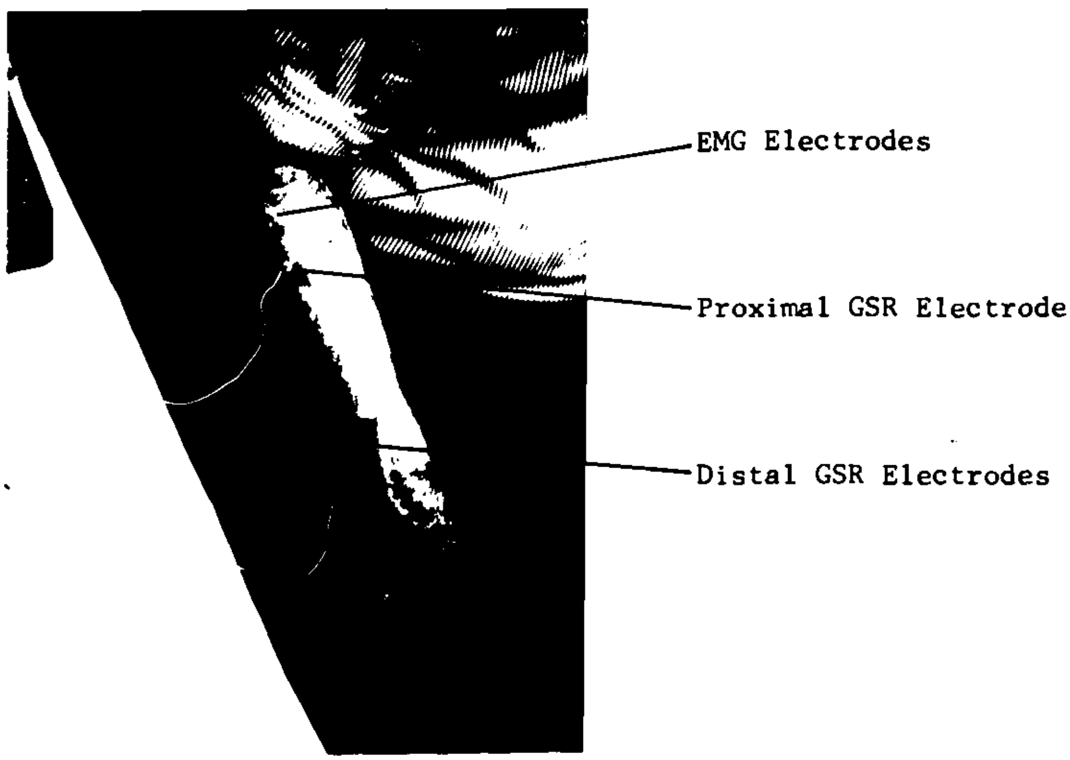



Figure 6. Locations of GSR and EMG Electrodes.

# CHAPTER V

# RESULTS AND ANALYSIS

## Results

After a number of trials of the experiment had been carried out it became apparent that the EMG recordings of subjects who were not able to successfully avoid allowing their middle finger to tremor while holding a weight showed significant variability. The tremor involved the use of other muscles than the extensor and apparently made it possible for the subject to hold the weight in very near the required position without using only the middle finger segment of the extensor digitorum communis. Whenever this situation came to the attention of the experimenter the subject was asked to devote particular attention to holding his finger still and in position but complete success was not attainable. This was caused by the subjects' inability to continue to overcome the effect of gravity on the weight. In these cases so much tremor was present that it resulted in rendering certain areas of the EMG record which were completely erroneous.

A possible source of error which may have led to incorrect EMG readings is any effect that change in skin surface conductance might have on the apparent voltage across the EMG electrodes. No research in this area could be found but it is a real possibility that could occur at any time surface electrodes are used to monitor the EMG. A solution to this problem would be to use implanted electrodes to measure the EMG. This would prevent, however, our integrated EMG from being meaningful as discussed previously since the monitoring would be of a very small region of one muscle rather than the whole muscle or major segment.

As can be seen in Table 1, there was significant variability among subjects in the muscle activity required to perform the same task and the length of time before full scale deflection of the GSR or exhaustion occurred while performing each task. Subjects I, III and IV actually used the most muscle activity in holding a lighter weight. While individual differences might be used to explain the length of time a subject could perform a given task, it seemed reasonable to anticipate that each subject would have to expend approximately the same per cent of maximal muscle activity per unit time to hold any weight. In contrast to this is the relatively low variability of the GSR variable among subjects and tasks during the course of the experimentation.

## Statistical Analysis

The experimental variables analyzed in this study are: (1) the frequency of integration of the EMG per minute where one integration was set to be the equivalent of one hundred microvolts of electrical activity and (2) the GSR as recorded in millimeters of deflection from the zero point of the strain gage. The EMG was recorded directly from the middle finger segment of the *extensor digitorum communis* of the subject's dominant arm while the GSR was recorded from the surface of the same arm.

These recordings were made while the subject was performing the isometric tasks mentioned previously. The integrated EMG was chosen as the independent variable in this study because of its reported high correlations with the tension actually produced by a muscle during voluntary isometric contraction. From this it should have been possible to observe the amount of muscle activity required to produce a known and observable work output.

In order to test the hypothesis that the GSR is a measure of human energy expenditure the data taken for each task for each subject was tested to determine if any relatively simple functional relationship between the EMG and GSR variables could be established. Should this be the case it would be logical to consider the GSR a promising measure of energy expenditure. Further research would be necessary in order to confirm this finding.

A computer program was utilized which calculated the mean and variance of both variables and determined the correlation coefficient for the two. A second program was used which attempted to fit the data by means of least square estimation to six different functions and also calculated an index of goodness of fit for each curve. The six functions were:

$$y = a + bx$$

$$y = a(e)^{bx}$$

$$y = a(x)^{b}$$

$$y = a + \frac{b}{x}$$

$$y = \frac{1}{a + bx}$$

$$y = \frac{x}{ax + b}$$

An index of 1.000 would mean that the least squares estimator found by the program for that particular function would describe the data without error.

The results of analysis of each of the sixteen trials are shown in Tables 2 and 3. In spite of the moderate correlation coefficients shown in Table 2 the value for the goodness of fit index in each case indicates a weak to negligible fit of the data by the best estimator of the six estimators tried. All sets of data had as their best estimator either a linear equation or a hyperbolic equation. The signs and relative magnitudes of the parameters of the equations exhibit some similarity but this was to be expected.

Table 1. Uncoded Values for Independent and Dependent Variables for Each Task for Each Subject

| Subject | Task | GSR (umhos) Start | GSR (umhos) Finish | EMG (integrations/min) Start | EMG (integrations/min) Finish | Elapsed Time (min). |
|---|---|---|---|---|---|---|
| I | I | 21.79 | 25.34 | 23 | 28 | 10.00 |
| | II | 22.29 | 23.49 | 6 | 7 | 11.55 |
| | III | 24.49 | 25.52 | 16 | 92 | 23.38 |
| | IV | 22.73 | 24.00 | 7 | 55 | 28.00 |
| II | I | 21.25 | 23.23 | 68 | 70 | 15.72 |
| | II | 24.65 | 26.76 | 13 | 31 | 14.88 |
| | III | 23.08 | 27.05 | 22 | 34 | 14.30 |
| | IV | 21.88 | 23.55 | 65 | 139 | 21.00 |
| III | I | 29.23 | 32.80 | 72 | 82 | 0.90 |
| | II | 28.36 | 31.25 | 46 | 38 | 6.71 |
| | III | 24.80 | 28.34 | 74 | 151 | 4.80 |
| | IV | 24.49 | 26.76 | 89 | 109 | 11.35 |
| IV | I | 22.44 | 23.23 | 20 | 35 | 18.88 |
| | II | 22.58 | 23.38 | 26 | 65 | 29.41 |
| | III | 24.00 | 25.17 | 24 | 47 | 18.81 |
| | IV | 37.27 | 38.53 | 29 | 59 | 13.91 |

Table 2. Results of Statistical Analyses of Experimental data for EMG and GSR

| Subject | Task | Correlation Coefficient | Form of Regression | Least Squares Regression Equation | Goodness of Fit Index |
|---|---|---|---|---|---|
| I | I | 0.62 | linear | $y = -1.29 + 0.36x$ | 0.384 |
| | II | 0.76 | hyperbolic | $y = 20.49 + (-93.77)/x$ | 0.610 |
| | III | 0.78 | hyperbolic | $y = 7.22 + (-144.86)/x$ | 0.707 |
| | IV | 0.84 | linear | $y = -3.45 + 0.27x$ | 0.701 |
| II | I | 0.73 | linear | $y = -3.23 + 0.19x$ | 0.531 |
| | II | 0.76 | linear | $y = -3.47 + 0.73x$ | 0.571 |
| | III | 0.61 | linear | $y = -10.22 + 0.45x$ | 0.368 |
| | IV | 0.79 | linear | $y = -3.47 + 0.73x$ | 0.632 |
| III | I | 0.39 | linear | $y = -6.46 + 0.22x$ | 0.150 |
| | II | 0.50 | hyperbolic | $y = 36.97 + (1077.46)/x$ | 0.282 |
| | III | 0.80 | linear | $y = -12.48 + 0.20x$ | 0.641 |
| | IV | 0.21 | linear | $y = 0.30 + 0.041x$ | 0.046 |
| IV | I | 0.45 | hyperbolic | $y = 6.35 + (-77.14)/x$ | 0.377 |
| | II | 0.87 | hyperbolic | $y = 10.23 + (-227.36)/x$ | 0.805 |
| | III | 0.89 | linear | $y = -8.50 + 0.36x$ | 0.792 |
| | IV | 0.82 | linear | $y = -21.07 + 0.61x$ | 0.668 |

Table 3. Environmental Conditions in Experimental Room During Trials

| Subject | Task | Room Temperature ($^{o}C$) | Relative Humidity(%) | Barometric Pressure (inch Hg.) |
|---|---|---|---|---|
| I | I | 22.8 | 39 | 30.22 |
| | II | 27.2 | 44 | 30.10 |
| | III | 27.8 | 29 | 30.18 |
| | IV | 25. | 58 | 30.01 |
| II | I | 21.7 | 46 | 29.71 |
| | II | 24.4 | 46 | 30.26 |
| | III | 24.4 | 57 | 30.14 |
| | IV | 27.8 | 36 | 30.05 |
| III | I | 27.2 | 44 | 30.09 |
| | II | 25.6 | 48 | 30.26 |
| | III | 24.4 | 57 | 30.14 |
| | IV | 24.4 | 55 | 29.78 |
| IV | I | 22.8 | 8 | 30.24 |
| | II | 22.2 | 43 | 29.73 |
| | III | 24.4 | 30 | 30.13 |
| | IV | 25.6 | 52 | 29.80 |

# CHAPTER VI

## CONCLUSIONS AND RECOMMENDATIONS

On the basis of this experiment, it is reasonable to state that the Galvanic skin response does not appear to be a reliable measure of human energy expenditure. Perhaps the lack of any clear relationship between the two variables is caused by the EMG being solely a physical variable and the GSR a psychosomatic variable. If the precautions taken to prevent emotional reactions during the course of the experimentation were inadequate or the choice of tasks not suitable for eliciting a GSR caused only by physical conditions the resulting GSR would present a combined effect rather than a reaction only to physical stress. A significantly longer period of acclimitization would aid in yielding true results if this were the case by allowing not only time for establishing a base line but also a longer period for psychological adjustment to the experimental situation.

Behavior of the variables in any given situation seemed to be as expected but elimination of the tremor in susceptible subjects would probably increase the validity of EMG records made and strengthen the experiment. This is because tremor involves many muscles and produces higher total EMG activity than the actual activity of the muscle being monitored. In future trials with the EMG it is recommended that tasks be utilized which eliminate the possibility of tremor.

One problem generated as the experiment progressed was the high variability shown by different subjects as regards different tasks. The muscle activity required to perform the tasks varied significantly from subject to subject and often more weight was held with less muscle activity. The length of time required to produce exhaustion or a full scale GSR deflection likewise varied unrealistically from subject to subject for the same task.

Perhaps the results obtained were the result of the integrated EMG being unsuitable for measuring the results of the tasks utilized in this experiment. The principal flaw, of course, was that only one muscle was monitored and subjects apparently used more than that one muscle after appreciable fatigue was generated. If all muscles that might have been used in the activity had been monitored it might be that their summated activity would have produced a higher correlation with the GSR.

Before any further use is made of the integrated EMG in research concerning physiological work measurement, it is highly recommended that a number of experiments be run with a large number of subjects and tasks of varying natures in order to learn something of a general nature about the behavior of the integrated EMG during fatigue. Monitoring of more than the principal muscle involved in any task would seem imperative. With such an approach it might be possible to develop a general measuring procedure for physiological cost of work using the integrated EMG. At the present, it would seem that insufficient information is available to allow the general use of the integrated EMG as a measure of fatigue. It is suggested, however, that in the interim the GSR be correlated, if possible, with reliable measures of energy expenditure such as the pulmonary ventilation rate in order to gain a better understanding of what it indicates regarding energy expenditure.

A simple tapping exercise involving raising and lowering the finger to the beat of a metronome would make use of the _extensor digitorum communis_ and the _flexor digitorum profundus_ and quickly fatigue most subjects. This exercise would be one of the simplest that could be used with the EMG and would provide clear records for analysis without the need of concern about tremor due to straining any muscle with an applied tension. A more complex exercise that might be of value would be clutching a hand dynamometer with a grip of known strength. This would involve the _flexor sublimus_ the _palmar interosseus_ and the _flexor digitorum profundus_.

APPENDIX

Table 4. Mean and Variance of EMG Data

| Subject | Task | Mean | Variance |
|---|---|---|---|
| I | I | 24.92 | 123.97 |
| | II | 7.40 | 6.33 |
| | III | 41.73 | 566.86 |
| | IV | 32.42 | 346.35 |
| II | I | 45.38 | 196.69 |
| | II | 15.45 | 41.95 |
| | III | 34.80 | 106.12 |
| | IV | 64.09 | 639.31 |
| III | I | 60.43 | 157.31 |
| | II | 38.25 | 27.71 |
| | III | 103.53 | 1002.21 |
| | IV | 98.50 | 240.09 |
| IV | I | 34.11 | 90.24 |
| | II | 32.85 | 193.55 |
| | III | 34.45 | 108.78 |
| | IV | 45.88 | 155.78 |

Table 5. Mean and Variance of GSR Data

| Subject | Task | Mean | Variance |
|---|---|---|---|
| I | I | 7.68 | 41.85 |
| | II | 6.40 | 38.47 |
| | III | 2.67 | 7.23 |
| | IV | 5.24 | 35.53 |
| II | I | 5.35 | 13.24 |
| | II | 7.88 | 39.64 |
| | III | 5.40 | 58.20 |
| | IV | 3.91 | 17.76 |
| III | I | 6.90 | 51.44 |
| | II | 8.28 | 55.53 |
| | III | 7.84 | 60.31 |
| | IV | 4.33 | 8.76 |
| IV | I | 3.89 | 1.99 |
| | II | 2.41 | 7.75 |
| | III | 3.77 | 17.47 |
| | IV | 6.88 | 86.58 |

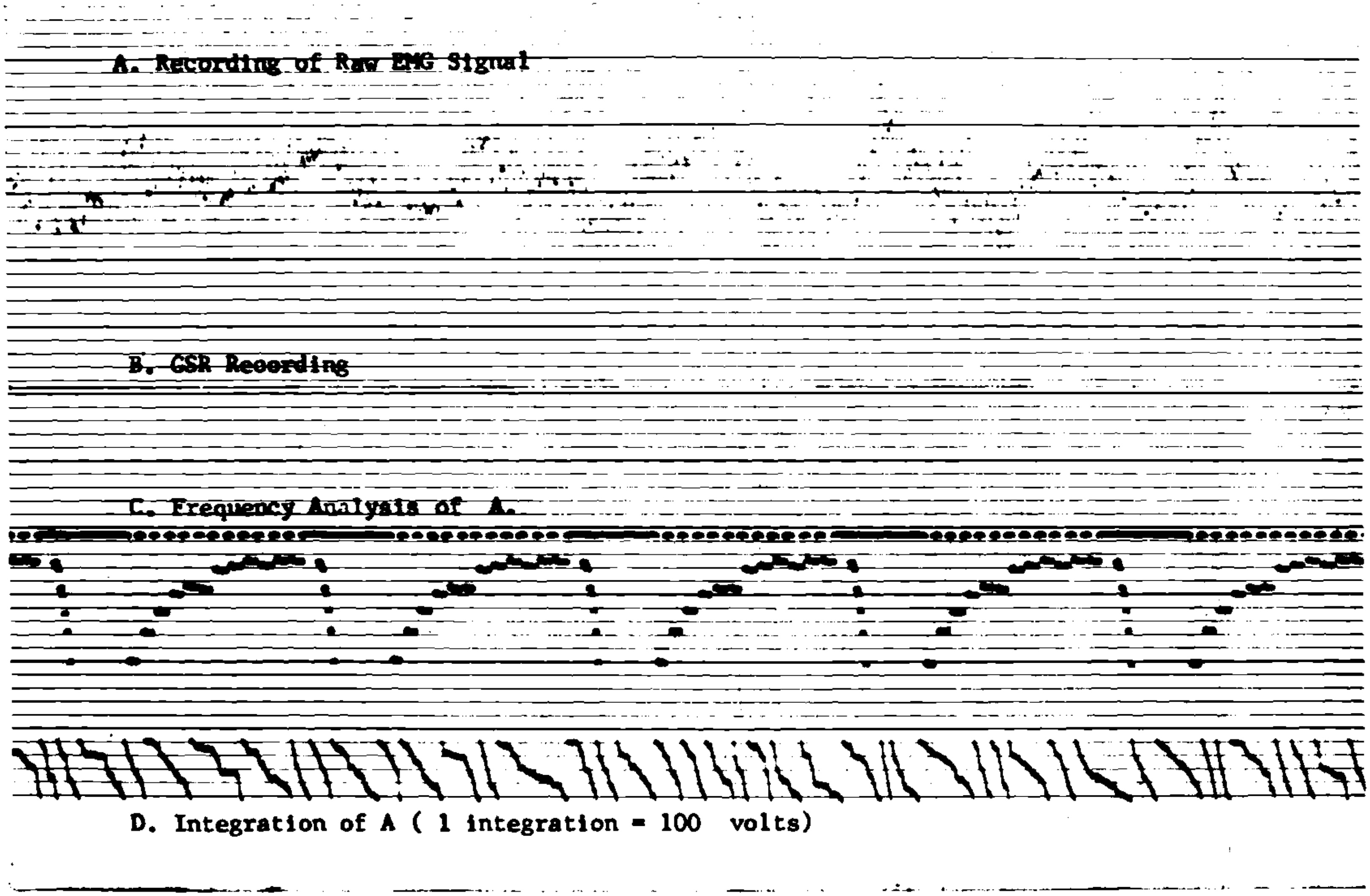



Figure 7. Sample Visicorder Recording of GSR and EMG.

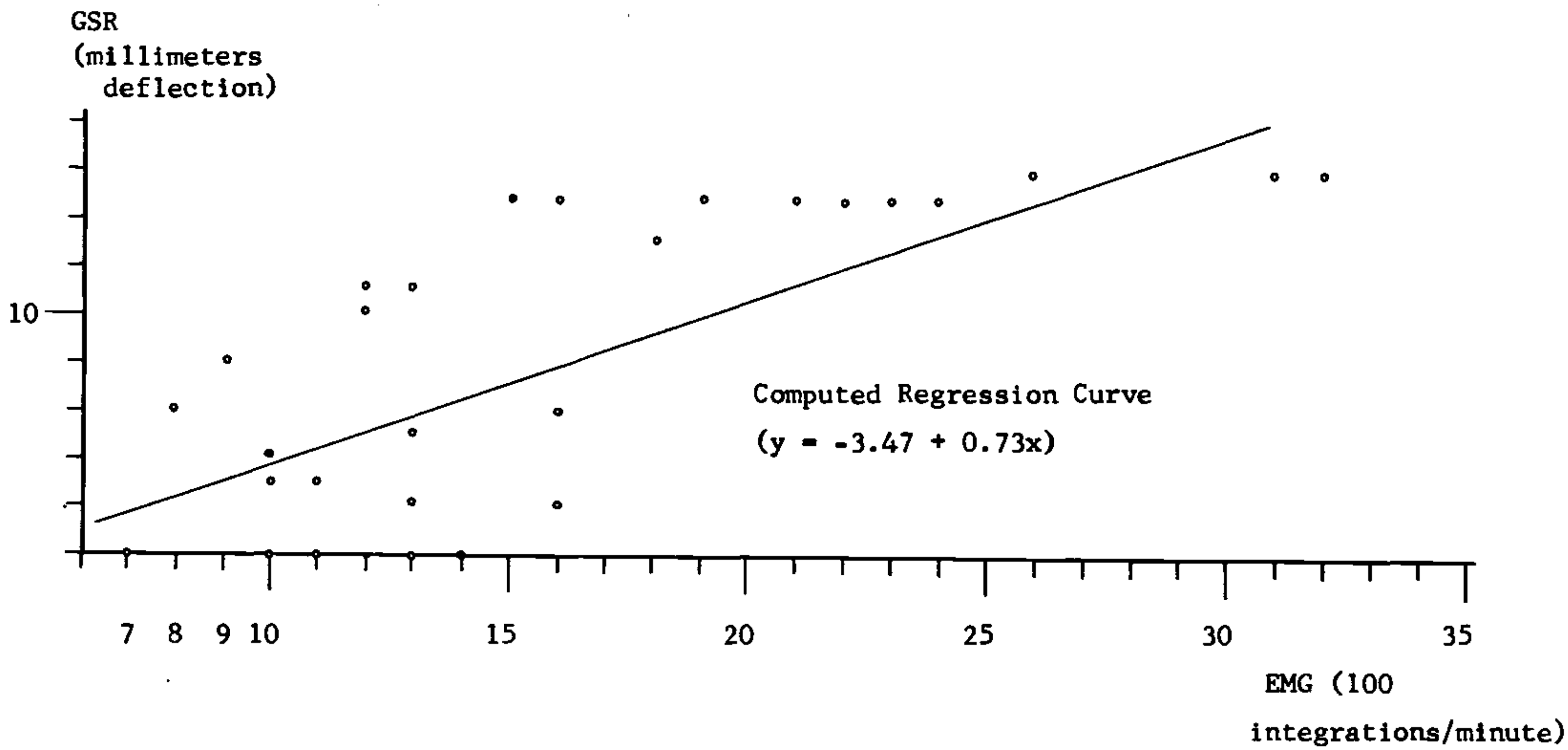



Figure 8. Sample Experimental Results for Dependent and Independent Variables (Subject II, Task II).

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